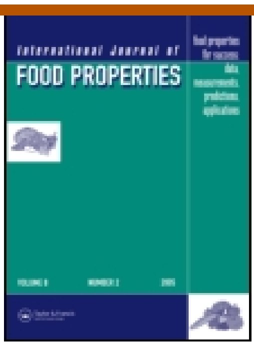

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Kinetic of Color Changes in Almond (Akbadem Variety) During Roasting and Storage

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In this research, the color change kinetics of the Akbadem variety during roasting and storage processes was investigated. The roasting process was carried out at three different temperatures (150, 160, and 170°C) and four different times 10, 20, 30, and 40 min. Then, roasted samples were separated in two groups and stored for 6 months in 4 and 22°C. All of the color parameters reactions during roasting and storage took place according to first order reaction kinetics. *L*- and hue angle-values tended to decrease linear significantly during roasting. The *L*-values of Akbadem samples roasted at 150, 160,and 170°C for 40 min was determined as 52.34 ± 2.53, 47.96 ± 1.35, and 43.17 ± 0.09, respectively. The highest *Ea*-value was determined on the *L*-value as 14.80 ± 4.26. The *a, b, ΔE*, metric chroma (C), and metric saturation (S) values increased during roasting. *L*-, *C*-, *a*-, *b*-, and *S*-values tended to decrease linear significantly during storage. The *L*-, *a*-, and *b*-values of Akbadem samples which were roasted at 170°C and stored at 4°C for 6 months were decreased from 43.17 ± 0.09, 14.25 ± 0.026, and 29.53 ± 0.06 to 34.91 ± 0.13, 10.06 ± 0.15, and 15.93 ± 0.12, respectively. According to sensory analysis, the panelists gave low scores as taste (1.9 ± 0.88), color (2.1 ± 0.57), and flavor (2.4 ± 0.7) for Akbadem samples roasted at 170°C for 40 min. ΔE was increased during storage Ea-values were decreased during roasting and storage at 4 and 22°C for 6 months.

Keywords: Almond, Roasting, Kinetics, Color, Storage, Snack foods.

INTRODUCTION

Almonds (*Prunus amygdalis var. dulcis*) are members of the family *Rosaceae* and the fruit is classified as a drupe in which the edible seed or kernel is the commercial product.[1] Almonds originated in the Middle East and have been cultivated for 4000 years.[2–6] It is believed to have originated in Middle East but is now grown more widely, including in southern Europe, Africa, Southern Australia, and California.[7] Almond cultivation in Turkey is concentrated in the Aegean region. Datça Peninsula, cultivated radiant, white, row almond, etc., as varieties, is the most

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widely grown in the Aegean region. Aegean region in terms of number of trees and almond production takes first place in Turkey. The Akbadem variety meets 30% of the production of almonds throughout the Aegean region of Turkey.[8–11] Akbadem efficiency varies according to the climatic conditions. Fifty tons of Akbadem have been obtained due to the cold weather in Datça region in 2015. Two hundred fifty to three hundred tons of goods can be achieved at favorable weather conditions.[12]

The U.S. almond production ranks first in the world (731.236.00 tons). The United States has been declared as one of the most important export product of the agricultural economy. Turkey ranks seventh in the world almond production with 69.838.00 tons.[13] Almonds are the most important nut tree crop worldwide in terms of commercial production.[14,15] It is a major nut tree crop in countries of Mediterranean basin. Turkey has rich almond genetic resources.[16] In recent years, production of almonds in Turkey has increased considerably, where cultivation has increased, due to the improvement of agricultural techniques and selection of new almond cultivars.[16]

Almonds are a good source of nutrients such as vitamin E, monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), arginine, and magnesium.[11,17] Almonds also contain considerable amounts of potential prebiotic indigestible carbohydrates. Almond cultivars commercial quality refers to all aspects related to the external presentation of the product, including size, shape, surface texture, kernel color, absence of double kernels, and ultimately, marketable yield. Sensory or organoleptic quality refers to those factors that determine consumer preference and, thus, is subjective and highly variable, while nutritional quality refers to the specific nutrients provided and the overall contribution to consumer health.[18]

Shelled nuts undergo processes including blanching, dicing, coating, roasting, and grinding to fit product formulation needs or give them increased consumer appeal. Roasting is one of the most important processes giving the product the necessary alterations to become value-added nuts.[19,20] Almonds kernels are sold raw or roasted and are consumed in a wide variety of foods including baked foods, cereals, and confectionaries. Dry roasting (hot air [HA]) is a common thermal process used by the almond industry.[21] There are several objectives to almonds roasting; one is to ensure that the center of every nut reaches some minimum temperature to destroy any toxins or allergens that may exist.[22] Another objective of almonds roasting is to give the product surface a variety of colors such dark roast or very dark roast.[23] Roasting alters and significantly enhances the flavor, color, texture, and appearance of almonds. Roasting also inactivates enzymes that speed up nutrient loss and destroys undesirable microorganisms and food contaminants. Therefore, from the quality and safety point-of-view, the times and temperatures applied are very important factors in almonds roasting. Common temperatures used for dry roasting range from 130 to 150°C. At 130°C it takes 40–55 min to obtain a light to medium roast product while at the higher temperature of 150°C it takes 10–15 min.[21]

Color is important for the consumer acceptance as well as being the indicator of the brown pigments formed during non-enzymatic browning and caramelization process.[24] Modeling the color changes during thermal processing may be useful in monitoring the quality of the final product.[25–27] The non-enzymatic browning is occur at of reactions including the pathways of sugar caramelization, Maillard reaction and oxidation of ascorbic acid. The Maillard reaction involves the reaction between the carbonyl group of a reducing sugar with a free, uncharged amine group of an amino acid or protein with the loss of one mol of water.[25,28,29] The foods show different browning properties according to their composition.[30] Color sorting technology has been in use commercially since 1930 and continues to show promising potentials in various applications in the food industry.[31] Non-enzymatic browning has a diminishing effect on the nutritional value due to the decreased protein digestibility and loss of essential amino acids. [25,32,33]Non-enzymatic browning reactions in food systems are generally considered to be zero- or first-order reactions. According to Heldman and Lund,[34] color changes can be modeled by using a first-order reaction rate and the effect of temperature on non-enzymatic browning reaction rate is usually expressed using an Arrhenius-type relationship. In order to take into account internal browning (the difference in *L*-value between whole nut surface color and ground nut color is of the order of 20%), the roasting process should be monitored using the *L*-value representing the lightness of almonds. Quality control of the heated product can be done using color analysis.[25,35] The purpose of this study was to analyze color kinetics data for almonds obtained during roasting and storage in terms of time and temperature.

MATERIALS AND METHODS

Samples and Roasting

Freshly harvested raw almonds in shell (Akbadem) were supplied from the "Sındı Village Agricultural Development Cooperatives" (Datça/Muğla/Turkey). Prior to roasting, almonds were dehulled. Almond kernels were roasted by using forced air laboratory scale (80 × 110 × 50 cm) rotary drum roasting machine (Alfer Mühendislik, Turkey) at three different air temperatures (150, 160, and 170° C) and using four different roasting times (10, 20, 30, and 40 min). Drum dimensions (diameter and length) is 20 × 25 cm and is capable of roasting up to 2 kg samples. The temperature sensitive of the device is ±1°C. Roasting temperature can be set between 100–300°C. All combinations of roasting were adjusted as 20 rev/min of the drum speed. At the end of each experiment, the roasted almonds were removed from the oven and cooled to room temperature and placed in the incubator until the color analysis was undertaken off-line. Then roasted almond kernels were stored in plastic polyethylene (PE) bags at two different storage temperatures (4 and 22°C) until analysis (2nd, 4th, and 6th month). A black and white picture of roasted and grounded almond examples were shown in Fig. 1.

Color Measurements

Examples of roasted almonds (40 g) were finely ground for color analysis in the grinder. Color analyzes were performed as triplicate. The color of the roasted samples was measured using a Color Flex CX2733 Hunter Lab (Hunter Associates Laboratory, USA). The *L-, a-*, and *b*-values are the three dimensions of the measured color which gives specific color value of the material. The *L*-value represents light ± dark spectrum with a range from 0 (black) to 100 (white). The *a*-value represents the green ± red spectrum with a range from –60 (green) to +60 (red). The *b*-value represents blue ± yellow spectrum with a range from –60 (blue) to +60 (yellow).[36,37] These values are dependent on measurement factors such as the type and size of the material, the angle of the measurements and the stability of the reference standards.[37]

Moisture and Ash Analysis

Moisture was determined by gravimetrically using moisture analyzer (OHAUS MB45, USA) at 105°C, ash amount was performed according to AOAC[38] method using burning in a furnace (Nuve MF 110, Turkey) at 650 ± 25°C.

Protein Analysis

Total protein was determined by nitrogen determination according to Dumas method (combustion) using nitrogen analyzer (NDA 701, Italy).

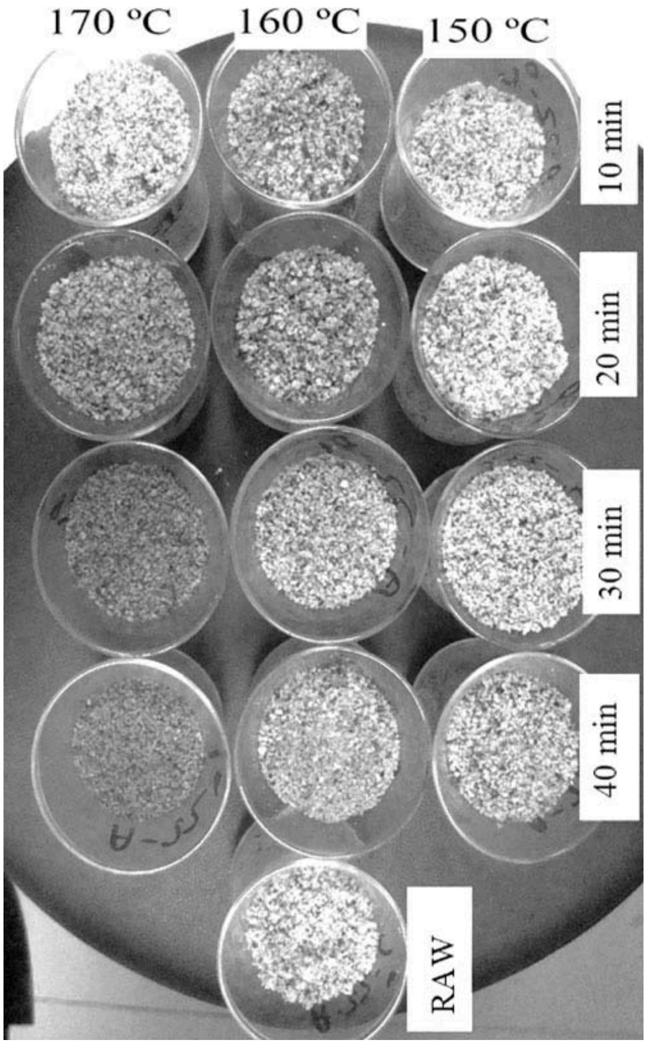


FIGURE 1 Examples of roasted and ground Akbadem.

Total Oil Analysis

Total oil was performed according to AOAC[39] method using Soxhlet extraction systems (Gerhart Soxtherm Multistat, UK). Results were expressed as the average of duplicate samples.

Sensory Evaluation

Sensory analysis was conducted by ranging from ages 25–50, 5 male and 5 female trained panelists.[40] Almonds appearance was assessed under white artificial illumination. The panelists were asked to indicate the degrees of liking of almonds on a 5-point scale with 1 being "dislike extremely" and 5 being "like extremely." Sensory analyses were carried out on raw and roasted almond samples during storage. Color, flavor, mouthfeel, and taste properties of the samples were evaluated by the panelists.

Data Analysis

The color change in roasted almonds was calculated by using Eqs. (1) and (2) for a first-order reaction given below and the effect of temperature on the rate of reaction was determined from the linearized Arrhenius Eq. (3). Total color difference (ΔE) in Hunter *a-, b-*, and *L*-values were determined using Eq. (4). Q_{10}: Eq. (5), chroma (C): Eq. (6), hue angle (H): Eq. (7), and metric saturation (S): Eq. (8) were calculated from the Hunter *L-, a-, b*-values and used to describe the color change during roasting and storage;

$$-d[C]/dt = k[C_0]^m \tag{1}$$

where [Q] is the quantitative value of the component under consideration, k is the reaction rate constant ($\min^{-1}$). The equation for first order kinetics after integration of Eq. (1) can be writen as:

$$LnC = LnC_0 - kt \tag{2}$$

where $[C_0]$ is the initial concentration content and C is the concentration after t-minute of heating at a given temperature.

$$k = k_0 \times e^{-\mathrm{Ea/RT}} \tag{3}$$

where k_0 is the frequency factor, E_a is the activation energy in cal/mole, R is the gas constant = 1.987 cal/°K mole = 8,314 J/mol °K, and T is the absolute temperature in °K. Regressing the logarithm of the rate constants, etc., reciprocal of absolute temperature, the slope and intercept were obtained using least squares linear regression.

$$\Delta E = \left[(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2\right]^{1/2} \tag{4}$$

where ΔE represents the total color difference; L_0 the lightness value at time zero, a_0 the redness value at time zero, b_0 the yellowness value at time zero; L the lightness value at time *t, a* the redness value at time t, and b the yellowness value at time t. The Arrhenius model or Q_{10} model can be used to describe how much faster a reaction will go if the product is held at some other temperature, including high abuse temperatures. If the temperature-accelerating factor is given, then extrapolation to lower temperatures, such as those found during distribution, could be used to predict expected product shelf life. This accelerating factor is sometimes called the Q10 factor[41] and is defined as:

$$Q_{10} = (k_2/k_1)^{10}/T_2 - T_1 \tag{5}$$

where T is temperature in °C, k_1 is the rate at temperature T_1 (°C), k_2 is the rate at T_2 (°C).

$$Chroma(C) = \left[(a)^2 + (b)^2\right]^{1/2} \tag{6}$$

$$Hueangle(H) = arctanb/a \tag{7}$$

$$Metric\,saturation(S) = \left(a^2 + b^2\right)/L \tag{8}$$

where L is the lightness value at time *t, a* is the redness value at time t, and b is the yellowness value at time t.

Statistical Analysis of Color

Statistical analysis of the data was performed using Minitab V.16. The color data were statistically analyzed using to find out the effect of each heating parameter analysis of variance (ANOVA) revealed a significant effect ($p < 0.05$; i.e., time and temperature) on the *L-, a-, b*-values of the heat-treated and stored samples, data means were compared by the Tukey's new multiple range test.

RESULTS AND DISCUSSION

Chemical and Physical Composition of Raw Almonds

Oils and proteins are the most intensive components of almonds. Variability in oil content and fatty acid composition, as well as tocopherol (vitamin E) content, depends mainly on the almond genotype.[42] The chemical properties of Akbadem samples shows similarity to the literature. Sathe[43] reported moisture, protein, fat, and ash content of the major almonds maketing in the United States as between 4.35–5.86, 16.42–22.17, 53.59–56.05, and 2.69–2.93%, respectively. Yildirim et al.[44] reported total oil content, protein content, ash content, humidity content of the selected 14 almond genotypes in Isparta/Turkey province as between 44.25–54.68, 21.23–35.2, 2.75–3.81, and 3.41–4.52%, respectively. The shell color of Akbadem is quite dark. The color is observed in *L*-value which is indicative of the brightness value as shown in Table 1. Dimensional characteristics of the Akbadem seed were found higher than other almond seed. Simsek et al.[45] Fruit weight with shell, kernel weight and kernel ratio of five almond types were found as 0.67 to 2.07 g, 0.44 to 1.18 g, and 44.44–59.29%, respectively.

Kinetics of Color Change During Heating

The data are plotted with quality factor on the *y*-axis versus time on the *x*-axis. Because a straight line is not produced on linear coordinates, it was determined that the reaction is not zero-order. It can be seen (Fig. 2) that the plot of the logarithm of *L, a*, and *b* remaining (LnCt/C0) versus time yielded, in all cases, good straight lines, which indicates a first-order reaction. Also the data was controlled for second order reaction kinetics, but a straight line is not produced on linear coordinates. Labuza and Riboh[41] pointed out that the most quality-related reaction rates are either zero or first-order reactions, and statistical differences between the two types may be insignificant.

Color parameters of almond samples before roasting was determined as *L*-value 62.96 ± 1.81, *a*-value 5.11 ± 0.93 and *b*-value 16.74 ± 0.76. The almond kernel color is found darker depending on the increase in the roasting temperature and roasting time, like the decrease of the *L*-value in Table 2. The *a*- and *b*-values increased depending on the increase in the roasting temperature and roasting time. The *L-, a*-, and *b*-values of Akbadem samples roasted at 150, 160, and 170°C for 40 min was determined as 52.34 ± 2.53, 47.96 ± 1.35, 43.17 ± 0.09; 9.52 ± 0.03, 11.96 ± 0.01, 14.25 ± 0.26; 24.25 ± 0.87, 28.71 ± 0.39, 29.53 ± 0.06, respectively. As shown in Table 2, it was observed that *L*-value was increased. On the other hand, *a*- and *b*-values decreased with the rest of the roasting times. Depending on the increases in roasting temperature, sensory properties were received low scores from the panelists. According to the results of sensory scores, the lowest

TABLE 1
Initial characteristics of raw almonds

Chemical and physical composition		*Size and gravimetric properties*	
Total oil (%)	53.93 ± 1.59	Surface area (mm^2)	533.90 ± 65.86
Protein (%)	20.57 ± 0.07	Length (mm)	28.25 ± 1.92
Moisture (%)	3.57 ± 0.15	Width (mm)	14.28 ± 1.17
Total ash (%)	3.19 ± 0.01	Thickness (mm)	6.87 ± 0.53
Water activity	0.38 ± 0.03	Weight (g)	1.38 ± 0.26
L	62.96 ± 1.81		
A	5.11 ± 0.93		
B	16.36 ± 0.76		

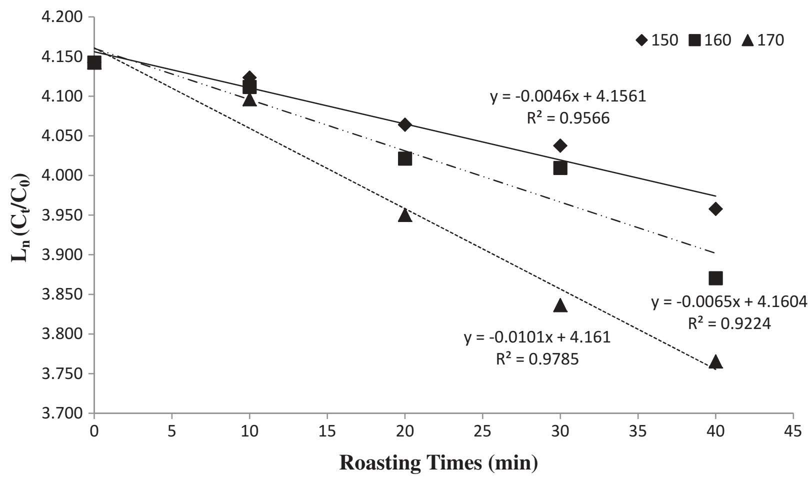


FIGURE 2 Kinetics of *L*-values of roasted almonds.

scores were obtained for the almond samples roasted at 170°C for 40 min. ($p < 0.01$). According to sensory analysis, the panelists gave low scores as taste (1.9 ± 0.88), color (2.1 ± 0.57), and flavor (2.4 ± 0.7) for the Akbadem samples roasted at 170°C for 40 min. All reactions were took place according to first order reaction kinetics as presented on the *L*-value in Fig. 2. Barreiro et al.[46] studied the kinetics of the color change of double concentrated tomato paste during heating. They found the degradation of the color parameter *L*-value according to first order reactions. The development of discoloration of samples during drying may be related to pigment destruction and non-enzymatic Maillard browning. The change in color during thermal processing of foods is postulated to take place by various mechanisms, including the degradation of pigments, oxidation of ascorbic acid, and the Maillard reaction. Kaftan[47] was investigated color degradation by Hunter colorimeter technique during roasting in an electrical oven of almonds cultivated in South Eagean region of Turkey. It was observed that the color change of roasted almonds followed first order reaction kinetics. The rate of change in brown color of almond was developed by Arrhenius equation as a function of temperature. The activation energy for roasted almonds was estimated to be 20,833 and 9151 kJ/mol on the basis of *a*- and *b*-values, respectively.

The total color difference (ΔE), which is a combination of parameters *L-, a-*, and *b*-values, is a colorimetric parameter extensively used to characterise the variation of colors in foods during processing. The chroma value indicates the degree of saturation of color and is proportional to the strength of the color.[48] The hue angle is frequently used to characterise color in food products. It has been extensively used in the evaluation of color parameters in green vegetables, fruits,and meats. The saturation index (S) that indicates color saturation and is proportional to its intensity-[36] The *L-, a-, b-*, ΔE-, C-, H-, and S-values are presented in terms of the velocity constant (k), energy of activation (E_a) and Q10 values in Table 3. The highest E_a-value was determined on the *L*-value to be 14.80 ± 4.26 ($p < 0.001$). The all color parameters showed linear regressions correlation coefficients (R^2) between 0.95 and 0.99. Yang et al.[33] roasted almond samples with infrared (IR), sequential infrared and hot air (SIRHA), and traditional HA. They reported that the total color change followed zero-order reaction kinetics and the activation energies were 73.58, 52.15, and 67.60 kJ/mol for HA, IR, and SIRHA roasting, respectively.

TABLE 2

L-, *a*-, and *b*-values of roasted almonds at different temperatures (150, 160, and 170°C) and times (10, 20, 30, and 40 min)

	Roasting temperature and roasting time (minute)											
	150°C				*160°C*				*170°C*			
	10	*20*	*30*	*40*	*10*	*20*	*30*	*40*	*10*	*20*	*30*	*40*
L	61.77 ± 0.54	58.21 ± 1.86	56.69 ± 0.58	52.34 ± 2.52	61.05 ± 0.55	55.77 ± 0.09	55.12 ± 1.36	47.96 ± 1.35	60.11 ± 2.24	51.94 ± 1.83	46.36 ± 0.67	43.17 ± 0.09
a	5.46 ± 0.13	6.21 ± 0.27	7.65 ± 0.06	9.52 ± 0.03	5.79 ± 0.45	7.54 ± 0.29	8.78 ± 0.24	11.96 ± 0.01	5.61 ± 0.06	9.23 ± 0.23	12.15 ± 0.15	14.25 ± 0.26
b	16.55 ± 0.35	17.87 ± 0.63	21.58 ± 0.29	24.25 ± 0.87	17.95 ± 0.33	20.62 ± 0.04	24.82 ± 0.02	28.71 ± 0.39	17.40 ± 0.10	24.28 ± 0.37	28.21 ± 0.32	29.53 ± 0.06

TABLE 3
First-order kinetic parameters for total color change of almonds during roasting with different temperatures (150, 160, and 170°C) and times (10, 20, 30, and 40 minutes)

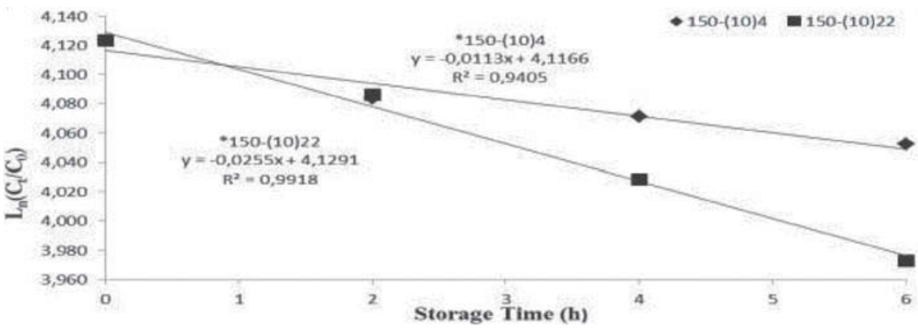
Color parameter	*Temp. (ºC)*	$k\times 10^3 (min^{-1})$	Q_{10} *(150–170°C)*	E_a *(Kcal mol^{-1})*	R^2
L	150	4.6 ± 0.0008	1.76 ± 0,29	14.80 ± 4.26	0.99 ± 0.0075
	160	6.5 ± 0.0009			
	170	10.1 ± 0.0006			
Δ*E*	150	71.7 ± 0.0008	1.13 ± 0.05	3.16 ± 1.15	0.97 ± 0.0377
	160	76.0 ± 0.0038			
	170	85.1 ± 0.0066			
Metric chroma (C)	150	10.9 ± 0.0004	1.42 ± 0.03	9.57 ± 0.59	0.98 ± 0.0085
	160	15.0 ± 0.0001			
	170	18.1 ± 0.0002			
Hue angle	150	1.3 ± 0.0003	1.90 ± 0.33	16.62 ± 4.36	0.95 ± 0.0155
	160	1.7 ± 0.0002			
	170	3.2 ± 0.0003			
a	150	15.8 ± 0.0001	1.49 ± 0.03	10.79 ± 0.55	0.99 ± 0.0003
	160	21.1 ± 0.0005			
	170	28.2 ± 0.0007			
b	150	10.5 ± 0.0008	1.38 ± 0.06	8.65 ± 1.22	0.96 ± 0.0049
	160	14.5 ± 0.0005			
	170	16.6 ± 0.0003			
Metric saturation (S)	150	26.8 ± 0.0022	1.46 ± 0.08	10.31 ± 1.58	0.99 ± 0.0025
	160	33.6 ± 0.0061			
	170	39.9 ± 0.0113			

Kinetics of Color Change During Storage

According to data of storage are plotted with quality factor on the *y*-axis versus time on the *x*-axis. Because a straight line is not produced on linear coordinates, it was determined that the reaction is not zero-order. It can be seen (Fig. 3) that the plot of the logarithm of *L, a*, and *b* remaining (LnCt/C0) versus time yielded, in all cases, good straight lines, which indicates a first-order reaction. Also the data was controlled for second order reaction kinetics, but a straight line is not produced on linear coordinates.

The almond samples were roasted at different temperatures and times and those were stored at 4°C (refrigerator) and 22°C (room temperature) for 6 months. The first roasting parameters were used as the control for storage parameters. The *k*-, Q_{10}-, E_a- and R^2-values of almonds roasted with different temperatures (150, 160, and 170°C) and times (10, 20, 30, and 40 min) are shown in Table 4. Mexis et al.[26] was investigated the effect of active and modified atmosphere packaging, container oxygen barrier and storage conditions on quality retention of raw ground almonds. A decrease at *L** parameter depending on decrease with a parallel increase ($p < 0.05$) of *a**- and *b**-values was observed after 12 months of storage. The most pronounced color changes was determined for samples in PET//LDPE pouches stored at 20°C.

The *L*-value of the almond kernel is found darker colorful at the end of both storage temperatures (4 and 22°C) according to preliminary roasting temperature ($p < 0.001$). The lowest *L*-value (34.91 ± 0.13) was obtained in almonds roasted at 170°C for 40 min and then stored at 4°C for 6 months. The *L*-value of the sample stored at 22°C is obtained as 39.23 ± 0.14. The *L-, a*-, and *b*-values of Akbadem samples which was roasted at 170°C and stored at 4°C for 6 months were decreased from 43.17 ± 0.09, 14.25 ± 0.026, and 29.53 ± 0.06 to 34.91 ± 0.13, 10.06 ± 0.15, and 15.93 ± 0.12, respectively. The *a*- and *b*-values increased at the end of the 4 and 22°C storage



* 150-(10)4: Almond samples roasted 150 °C for 10 minutes and stored at 4 °C

**150-(10)22: Almond samples roasted 150 °C for 10 minutes and stored at 22 °C

FIGURE 3 The results of *L*-value kinetics of roasting time against the storage time.

temperatures ($p < 0.001$). The scores of 1.9 ± 0.57, 1.8 ± 0.79, 1.6 ± 0.84; 1.6 ± 0.7, 1.5 ± 0.53, 1.4 ± 0.52 for color, flavor, and taste of Akbadem samples stored at 4 and 22°C were given by the panelists, respectively.

The rate constant (k), activation energy (E_a) and Q_{10}-values of *L, a, b*, Δ*E*, C, H, and S in roasted almonds during 4 and 22°C storage periods with different temperatures (150, 160, and 170°C) and times (10, 20, 30, and 40 min) are presented in Table 4. The highest E_a-value of the almond samples (roasted at 170°C and stored at 4°C) was determined as 21.28 ± 3.388 in *L*-value. The *L*-, H-, and *a*-values during 4°C storage periods were found to have increased depending on the roasting time at the E_a-value. The Δ*E*-, C-, *b*- and S-values during 4°C storage periods was found to have decreased depending on the roasting time at the E_a-value. Except for the *a*- and *b*-values, all values during 22°C storage periods were found similar. An increase in *b*-values were found during 22°C storage periods, while a decrease in a values. All of the color parameters showed linear regressions correlation coefficients (R^2) between 0.94 and 0.99. As shown in Fig. 3, the results of *L*-value kinetics of roasting time against the storage time was evaluated separately.

CONCLUSION

The almond roasting and storage conditions were assessed based on chromatic parameters. The roasting temperature and roasting time had too much influence on the color of almond as compared to storage. All parameters were influenced from roasting conditions. Results of *L-, a-*, and *b*-values showed that roasting temperature and roasting time produced more dark product. *L-, a-, b*-values and kinetic parameters proved to be good indicators of the total color change of roasted and stored almond. The final values of *L, a, b*, total color change (E), chroma, and hue angle were influenced by roasting and storage conditions. The color parameters in almond sample by roasting and storage was found to be a first-order reaction. The reaction rate was greatly influenced by roasting temperature and roasting time. The maximum browning rate occurred roasted at 170°C for 40 min. Examples of roasted almonds in high temperature conditions, according to the sensory analysis have received low scores. E_a-values were decreased significantly during roasting and at stored in 4 and 22°C. Kinetic models which can be applied to predict the quality changes in almond during roasting and storage as a function of time and temperature were developed. The color parameters of roasted almond

TABLE 4

First-order kinetic parameters for total color change during 4 and 22°C storage periods of almonds roasted with different temperatures (150, 160, and 170°C) and times (10, 20, 30, and 40 minutes)

		Storage periods (min)							
		10				20			
Color parameter	*Storage temprature (°C)*	$k \times 10^2$	Q_{10}	E_a	R^2	$k \times 10^2$	Q_{10}	E_a	R^2
L		1.57 ± 0.005	1.46 ± 0.057	10.32 ± 0.976	0.96 ± 0.039	1.61 ± 0.005	1.64 ± 0.074	13.20 ± 1.243	0.95 ± 0.005
Δ*E*		33.14 ± 0.043	1.96 ± 0.015	4.94 ± 0.376	0.97 ± 0.030	40.68 ± 0.030	1.11 ± 0.018	2.77 ± 0.445	0.96 ± 0.011
Metric chroma (C)		5.80 ± 0.013	1.39 ± 0.093	8.77 ± 1.804	0.94 ± 0.010	6.32 ± 0.005	1.12 ± 0.045	3.02 ± 1.111	0.99 ± 0.013
Hue angle	4	0.31 ± 0.001	2.56 ± 1,279	20.54 ± 3.442	0.95 ± 0.045	1.00 ± 0.004	1.74 ± 0.046	14.67 ± 0.661	0.96 ± 0.029
A		4.67 ± 0.006	1.18 ± 0.039	4.65 ± 0,911	0.98 ± 0.010	4.03 ± 0.003	1.12 ± 0.297	7.06 ± 0.275	0.96 ± 0.021
B		5.87 ± 0.016	1.46 ± 0.018	10.25 ± 0.284	0.95 ± 0.020	6.78 ± 0.007	1.14 ± 0.058	4.67 ± 1.405	0.99 ± 0.058
Metric saturation (S)		9.43 ± 0.017	1.28 ± 0.110	6.61 ± 220	0.97 ± 0.034	10.94 ± 0.005	1.07 ± 0.059	2.47 ± 1.195	0.98 ± 0.021
L		2.04 ± 0.005	0.73 ± 0.017	9.08 ± 0.624	0.96 ± 0.035	1.26 ± 0.002	0.83 ± 0.074	5.32 ± 1.693	0.97 ± 0.008
Δ*E*		37.04 ± 0.18	0.93 ± 0.008	1.89 ± 0.245	0.95 ± 0.022	65.79 ± 0.436	0.46 ± 0.031	17.95 ± 2.114	0.99 ± 0.016
Metric chroma (C)		5.43 ± 0.006	1.15 ± 0.051	3.94 ± 1.196	0.97 ± 0.036	5.94 ± 0.006	1.17 ± 0.041	4.25 ± 0.982	0.99 ± 0.18
Hue angle	22	0.6 ± 0.004	1.95 ± 0.403	17.34 ± 3.127	0.95 ± 0.033	0.61 ± 0.005	3.29 ± 0.815	29.84 ± 4.283	0.96 ± 0.010
A		3.94 ± 0.008	1.37 ± 0.189	8.37 ± 2.516	0.96 ± 0.037	4.3 ± 0.009	0.79 ± 0.144	3.89 ± 1.152	0.99 ± 0.012
B		5.69 ± 0.007	1.18 ± 0.047	4.65 ± 1.090	0.96 ± 0.027	6.18 ± 0.008	1.20 ± 0.038	5.04 ± 0.861	0.96 ± 0.032
MetricSaturation (S)		9.4 ± 0.021	1.36 ± 0.104	8.23 ± 2.043	0.96 ± 0.015	10.65 ± 0.012	1.18 ± 0.067	4.56 ± 1.551	0.97 ± 0.032

		Sorage periods (min)							
		30				40			
Color parameter	*Storage temprature (°C)*	$k \times 10^2$	Q_{10}	E_a	R^2	$k \times 10^2$	Q_{10}	E_a	R^2
L		2.43 ± 0.008	1.65 ± 0.076	13.4 ± 1.134	0.97 ± 0.024	2.37 ± 0.118	2.28 ± 0.324	21.28 ± 3.388	0.95 ± 0.005
Δ*E*		44.10 ± 0.029	1.09 ± 0.008	2.3 ± 0.261	0.99 ± 0.007	72.38 ± 0.367	0.51 ± 0.010	15.85 ± 1.432	0.96 ± 0.033
Metric chroma (C)		7.57 ± 0.006	1.11 ± 0.046	2.90 ± 1.156	0.97 ± 0.017	8.03 ± 0.014	1.26 ± 0.033	6.29 ± 0.715	0.99 ± 0.010
Hue angle	4	1.13 ± 0.002	1.29 ± .195	10.38 ± 2.161	0.96 ± 0.019	1.54 ± 0.004	1.45 ± 0.157	9.92 ± 1.054	0.95 ± 0.014
A		4.56 ± 0.007	1.22 ± 0.067	5.48 ± 1.491	0.99 ± 0.017	4.46 ± 0.010	1.34 ± 0.037	7.86 ± 0.715	0.95 ± 0.037
B		8.23 ± 0.009	1.15 ± 0.020	3.84 ± 0.495	0.98 ± 0.020	8.83 ± 0.017	1.49 ± 0.044	7.07 ± 0.902	0.98 ± 0.029
Metric saturation (S)		12.84 ± 0.010	1.11 ± 0.011	2.81 ± 0.282	0.96 ± 0.023	21.38 ± 0.119	2.10 ± 0.065	19.41 ± 0.615	0.95 ± 0.028
L		2.25 ± 0.005	0.75 ± 0.137	5.55 ± 1.085	0.98 ± 0.023	1.34 ± 0.002	1.23 ± 0.199	7.83 ± 1.319	0.96 ± 0.028
Δ*E*		40.97 ± 0.045	1.17 ± 0.089	3.45 ± 1.781	0.96 ± 0.038	41.62 ± 0.036	1.13 ± 0.018	3.27 ± 0.459	0.97 ± 0.026
Metric chroma (C)		6.52 ± 0.006	1.14 ± 0.083	3.61 ± 2.000	0.98 ± 0.031	7.22 ± 0.007	1.14 ± 0.045	3.68 ± 1.077	0.98 ± 0.017
Hue angle	22	1.04 ± 0.004	1.87 ± 0.257	16.56 ± 2.454	0.99 ± 0.010	1.37 ± 0.005	1.76 ± 0.109	15.23 ± 1.658	0.99 ± 0.014
A		3.65 ± 0.002	0.94 ± 0.034	1.63 ± 1.007	0.95 ± 0.034	4.17 ± 0.004	0.88 ± 0.030	3.67 ± 0.916	0.94 ± 0.041
B		7.08 ± 0.009	1.19 ± 0.096	4.69 ± 2.218	0.98 ± 0.019	8.02 ± 0.010	1.19 ± 0.033	6.21 ± 2.262	0.95 ± 0.048
Metric saturation (S)		11.11 ± 0.017	1.25 ± 0.189	5.82 ± 2.936	0.95 ± 0.028	21.63 ± .132	2.24 ± 0.192	20.89 ± 2.143	0.97 ± 0.009

*Kinetic modeling was carried out almond samples stored in 6 months. *L*, *a*, and *b* color values was measured at 2, 4, and 6 months. k: min^{-1}; Ea: (Kcal/mol).

were predicted by the use of kinetic models describing quality deterioration during storage as a function of roasting temperature and roasting time. Hunter color values may be used to predict the roasting and storage conditions of almond. Therefore, almond color may be used as a quality indicator for roasting and storage processing conditions. As a result; if the appropriate roasting and storage temperatures and times, which are the basic units of almond processing, used, creditable almond color, taste, and flavor characteristics are obtained. However, increasing roasting temperature and times and storage temperatures were negatively affected these properties. It is thought to be a model of this work for roasting and storage temperatures of different varieties of almonds. In future studies, the color characteristics of almonds is recommended to be considered along with acrylamide formation which is one of the important results of the nutrition and health terms of the Maillard reaction.

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